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# Knee Joint Angles and Spatio-Temporal Parameters Estimated via Wearable Inertial Sensors

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## Introduction

Gait analysis in medical practice is mostly done by camera-based motion analysis systems, which provide good results but presents serious drawbacks (costs, complexity). Thus, small-size low-cost wireless inertial sensors are an emerging tool for monitoring gait. Aim of the work is to implement a wireless inertial system, with 2 sensors (on thigh and shank), for evaluating joint angles plus spatio-temporal variables for several test. Results are promising and demonstrate the goodness of the realized system.

## Methods

Knee flexion/extension angles are calculated as follows:

1. Thigh/shank sensor frames aligned vertically/horizontally;
2. Orientation estimation;
3. Differential orientation, conversion into angle-axis representation, and joint angle extrapolation.

As per spatio-temporal parameters:

- Temporal events (toe-offs, heel-strikes, etc...) estimated from shin's gyro.
- Stride time (ST) estimated by measuring the time between two toe-offs.
- Stride length (SL) calculated with 2 approaches: geometrically with a human gait model (1st method), or directly integrating inertial signals (2nd one).
- Stride speed (SS) calculated by dividing SL and ST.

## Results

The system consists of 2 Tyndall Wireless Inertial Measurement Units (WIMUs) with 3D accelerometer/gyro (250 Hz) and WiFi. Algorithms are implemented in Matlab, and the test considered are walking, drop and Sit-to-Stand. As for spatio-temporal feature (Table I), SL/SS are similar with both methods, though the second one presents smaller mean errors but higher variability. Knee joint angles are validated (Fig. 1) with a high-speed camera. Results (Table I) show good repeatability and accuracy for all test (i.e. 3.9 deg for walking). Pearson's  $r$  is between 0.97-0.99.

## Conclusions

This work presents a wearable inertial system for the implementation of a complete gait analysis for a wide set of test. Overall results present good repeatability and the accuracy is comparable with the state-of-the-art.

Table I: Results

<b>Spatio-Temporal Parameters</b>			
<b>Actual SS (m/s)</b>	0.97	1.11	1.66
<b>ST (sec)</b>	$1.19 \pm 0.03$	$1.07 \pm 0.01$	$0.91 \pm 0.01$
<b>SL (m) – first method</b>	$1.02 \pm 0.02$	$1.03 \pm 0.02$	$1.48 \pm 0.025$
<b>SL (m) – second method</b>	$1.05 \pm 0.11$	$1.04 \pm 0.11$	$1.53 \pm 0.15$
<b>SS (m/s) – first method</b>	$0.87 \pm 0.02$	$0.96 \pm 0.02$	$1.62 \pm 0.025$
<b>SS (m/s) – second method</b>	$0.9 \pm 0.1$	$0.96 \pm 0.07$	$1.67 \pm 0.16$
<b>Knee Joint Angles</b>			
	<b>Mean error <math>\pm</math> st_dev (deg)</b>	<b>Pearson's r</b>	<b>RMSE (deg)</b>
<b>Walking (0.97 m/s)</b>	$2.28 \pm 2.2$	0.992	3.16
<b>Walking (1.11 m/s)</b>	$-0.89 \pm 3.91$	0.978	4.01
<b>Walking (1.66 m/s)</b>	$-1.85 \pm 4.18$	0.969	4.56
<b>Drop Test</b>	$4.92 \pm 7.11$	0.968	9.6
<b>STS Test</b>	$5.41 \pm 5.65$	0.972	7.81

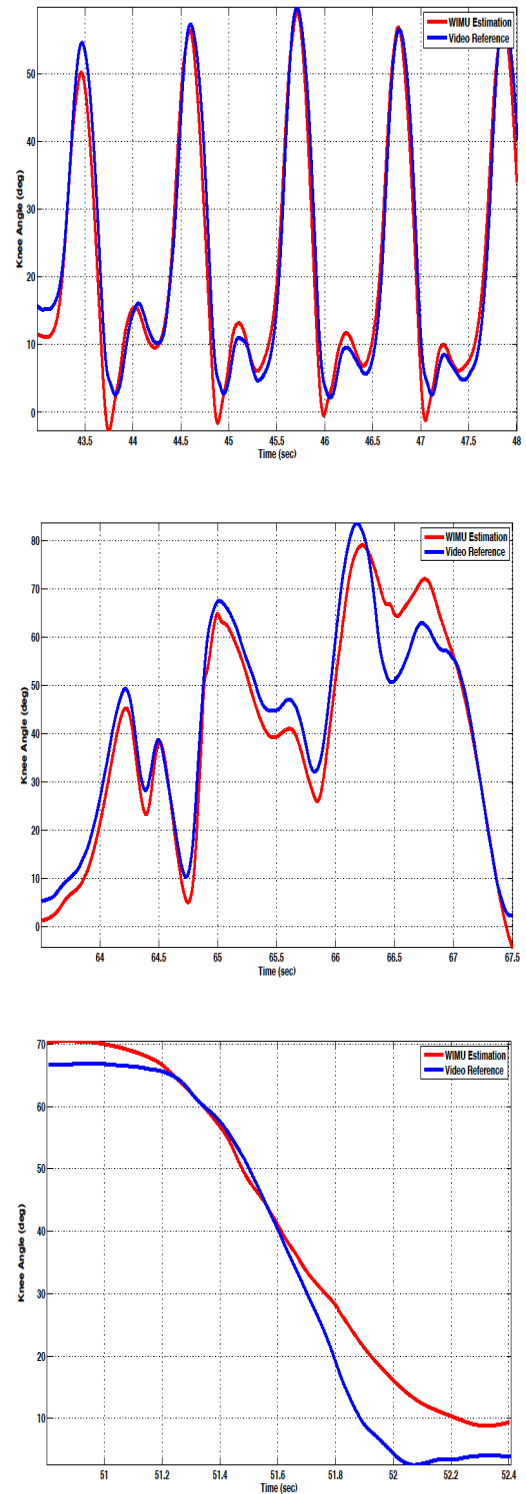


Fig. 1. Knee angles from WIMUs (red line) and camera (blue) for one subject performing walking test at 1.11 m/s (top), drop test (centre) and STS test (bottom).